



A method to account for surface BRDF effects on satellite UV/VIS algorithms

W. Qin¹, A. Vasilkov¹, N. Krotkov², L. Lamsal³,
D. Haffner¹, R. Spurr⁴, J. Joiner²

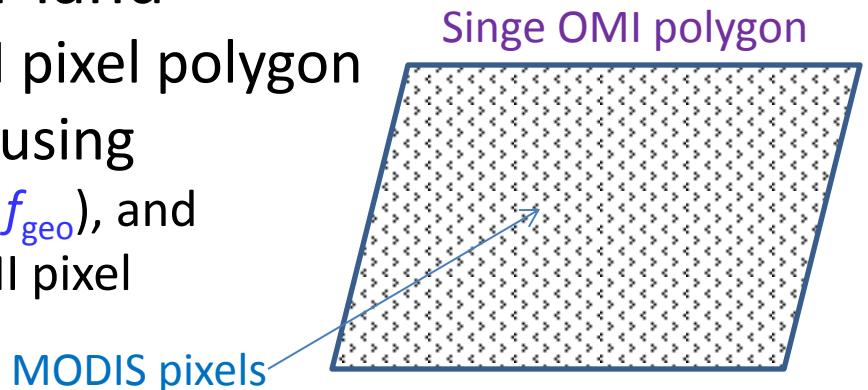
1. Science Systems and Applications, Inc.
2. NASA Goddard Space Flight Center
3. Universities Space Research Association
4. RT Solutions

Background

- LER (Lambertian Equivalent Reflectivity)
 - A quantity used in most satellite UV/VIS cloud, aerosol and trace-gas algorithms to specify the surface reflectivity
- Limitation of current LER products (OMI and TOMS)
 - Climatological and static, no sun-view geometry dependence
 - LER is sensitive to observation geometry because
 - surface is non-Lambertian and non-homogeneous
 - different pixels have different sun-view geometries and size of footprint
- Solution - geometry-dependent LER (GLER)
 - Account for surface BRDF and heterogeneity effects
 - No major change to existing operational satellite trace-gas and cloud algorithms that use the LER concept
- Topics covered in this talk
 - Land & water BRDF models used in GLER
 - How to handle mixed pixels
 - How to estimate pixel average terrain height using DEM data

MODIS land BRDF model

- BRDF – bidirectional reflectance distribution function; BRF – bidirectional reflectance factor
- MODIS kernel-driven model (linear model)
 - $\text{BRF} = f_{\text{iso}} + f_{\text{vol}} * k_{\text{vol}} + f_{\text{geo}} * k_{\text{geo}}$
 - Two kernels ($k_{\text{vol}}, k_{\text{geo}}$) -- angle dependent only (analytic function of SZA, VZA & RAA)
 - Three coeffs $f's$ -- wavelength and strong landcover dependent, specified by MODIS **MCD43GF (gap-filled, 30 arc-sec, every 8-day)**
- OMI pixel-based BRF over land
 - Average 3 coeffs over OMI pixel polygon
 - Calculate each pixel's BRF using
 - pixel avg coeffs ($f_{\text{iso}}, f_{\text{vol}}$ and f_{geo}), and
 - SZA, VZA and RAA from OMI pixel



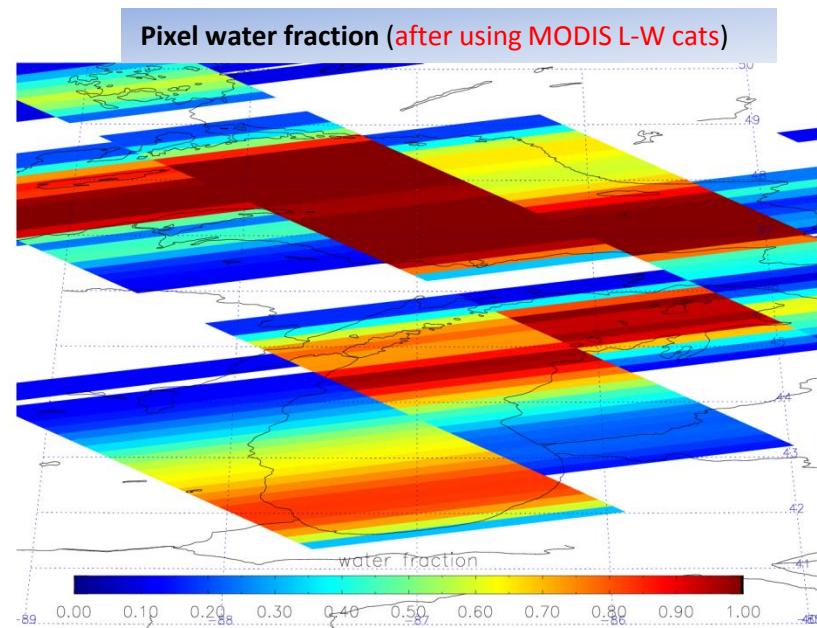
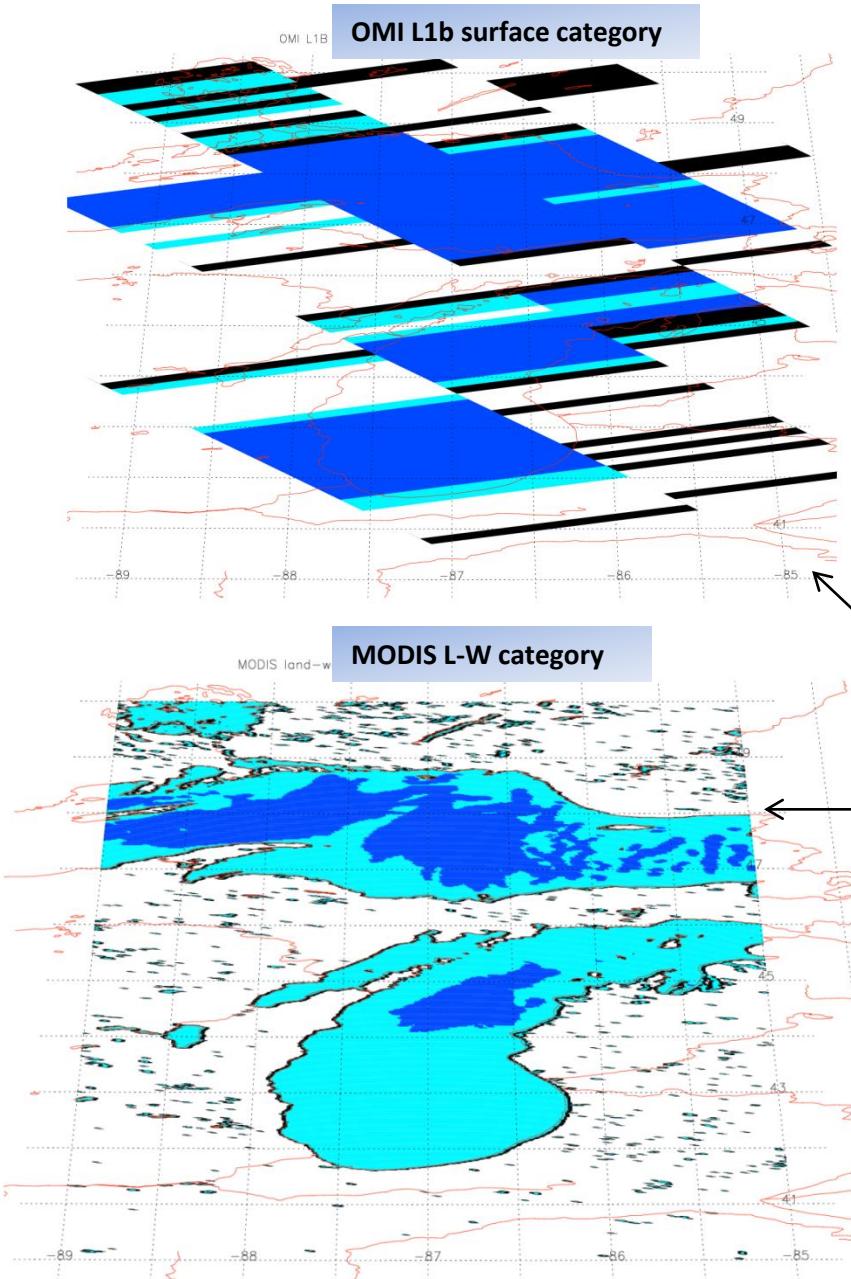
Ocean BRDF model

- Water surface specular reflection – Giss Cox-Munk model
 - full vector model for a rough water surface
- Water-leaving rad contribution
 - Case 1 water model with chlorophyll concentration as input (pixel average from 2.5 arc-min monthly climatology)
 - Considered interaction between downwelling atmospheric transmittance and water-leaving rad
 - implemented in the latest Vlidort 2.7a

Mixed pixels

- Pixels mixed with land & water: coastal zones and inland waters
 - Area weighted TOA rad $I_a = f_L \cdot I_{a, \text{land}} + (1-f_L) \cdot I_{a, \text{water}}$
 - $I_{a, \text{land}}$ – TOA rad calculated assuming land surface
 - $I_{a, \text{water}}$ – TOA rad calculated assuming water surface
 - f_L -- land fraction in the pixel
- Calculate f_L by applying **MODIS 30 arc-sec land water flag map** to OMI pixel polygons
 - Convert MODIS 8 surface category flags into binary mask (land or water) by merging all shorelines and ephemeral water into land category

Case study: Great lakes (orbit 12399)



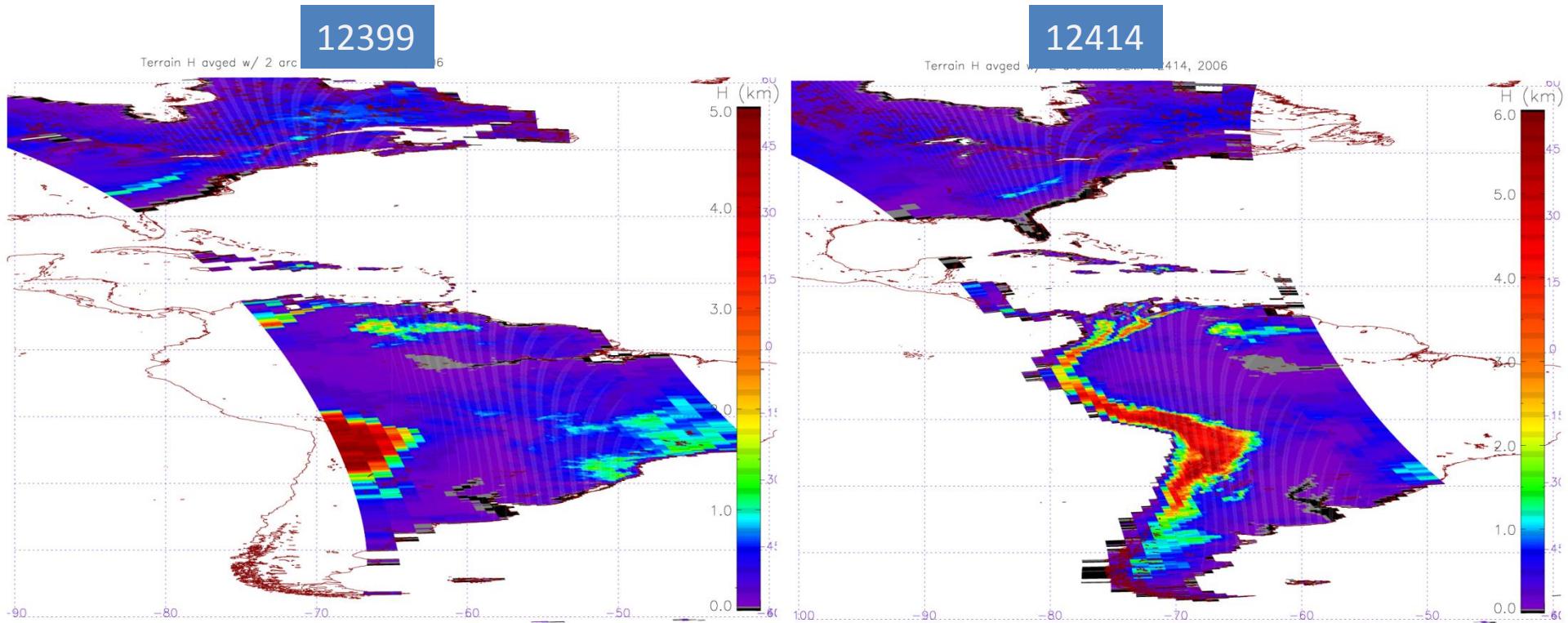
background - land
light blue - shallow inland water
dark blue - deep inland water
black - lake shores

- OMI surface category flags
 - ✓ misclassify lake shores
 - ✓ cannot handle mixed pixels (either classify as water or land pixels)
 - ✓ change with orbit

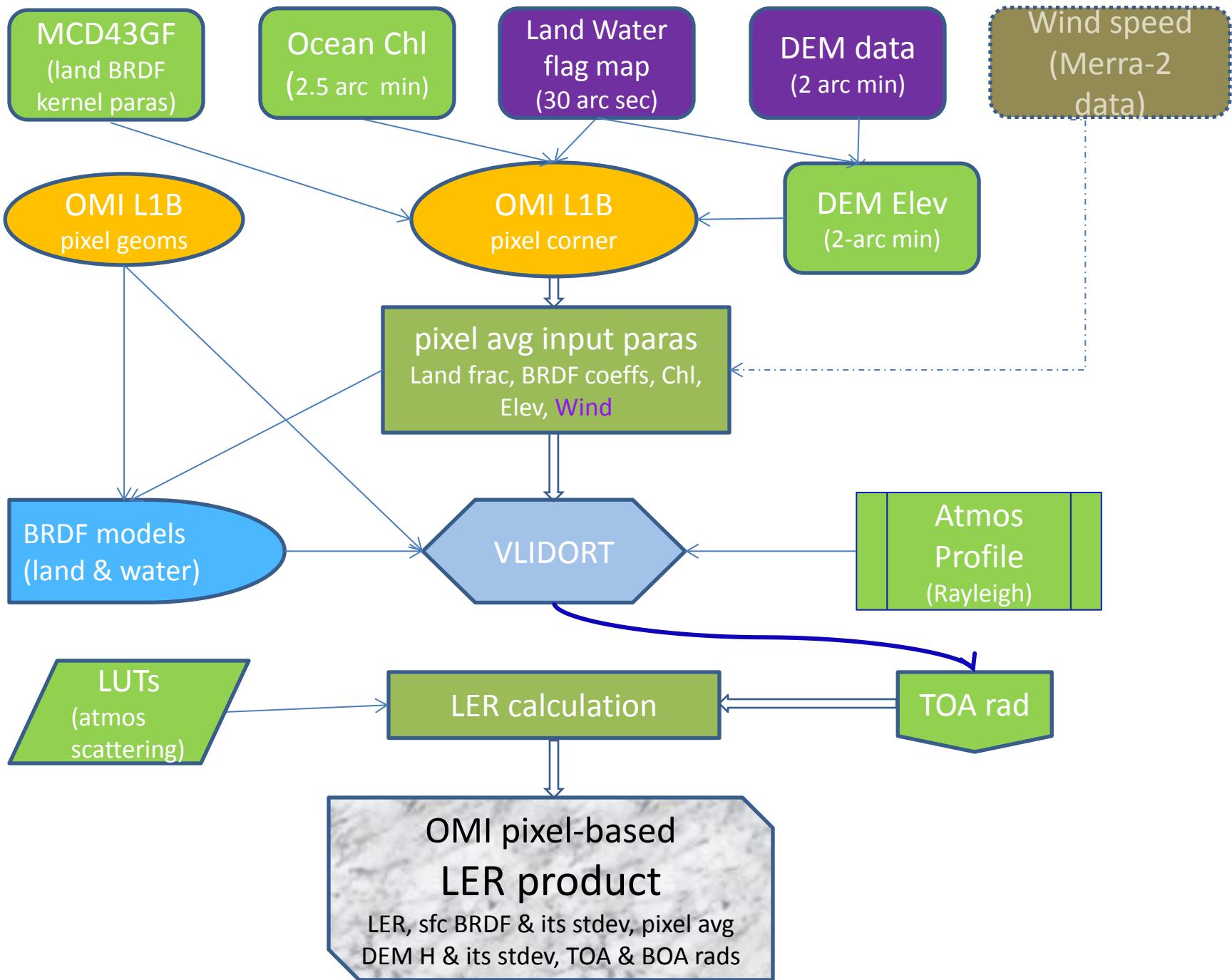
Terrain height calculation

- Issue with OMI L1B terrain height
 - It is the value at pixel center, not avg value over the pixel polygon which retrieval algorithms (No2, cloud) need
- Solution - replace OMI terrain height with pixel avg elevation calculated from DEM data
 - 2-arc min surface topographic data
 - above sea level - positive values (for most land surface)
 - below sea level - negative values (for ocean)
- Pre-process raw DEM data using MODIS 30 arc-sec Land-Water flag map
 - each DEM cell contains 4x4 Modis Land-Water flag values
 - keep all negative values over land and positive values over inland waters
 - zero out negative values over oceans
 - Average pre-processed DEM elevation data over OMI polygon

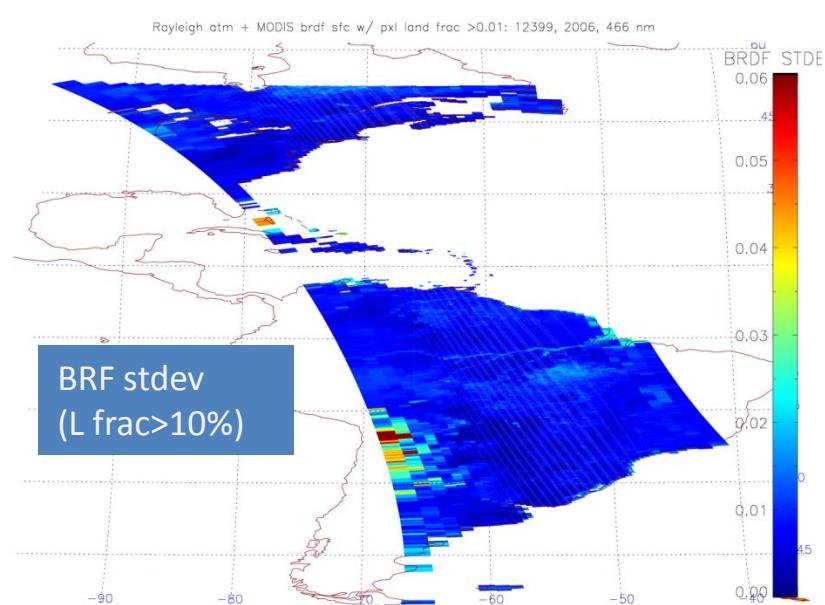
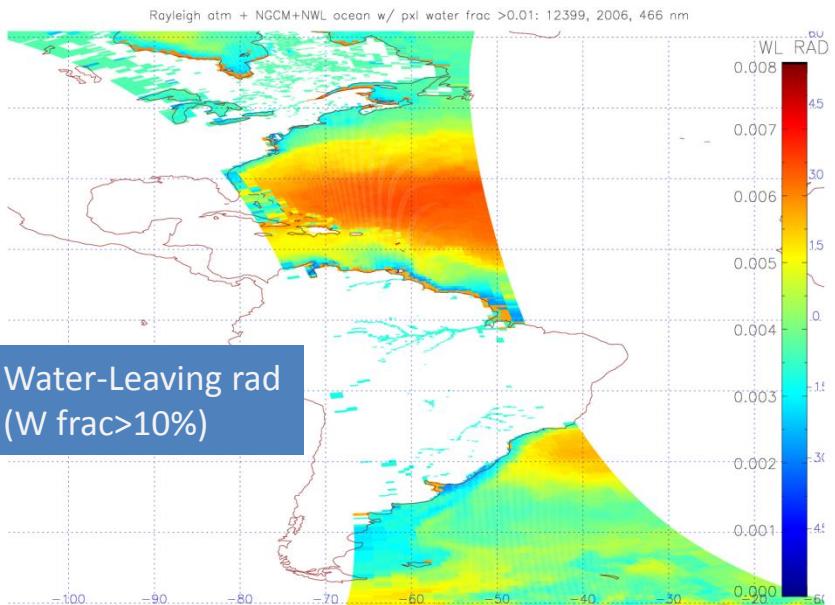
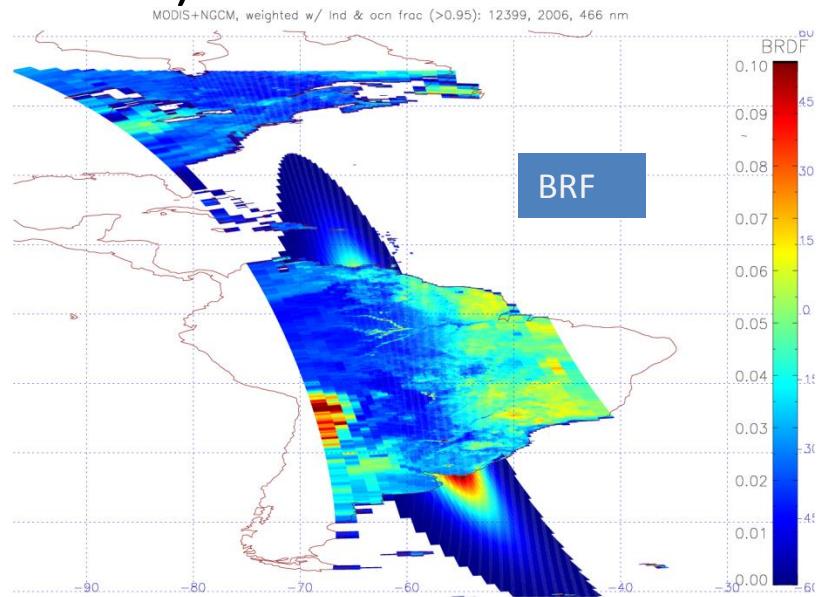
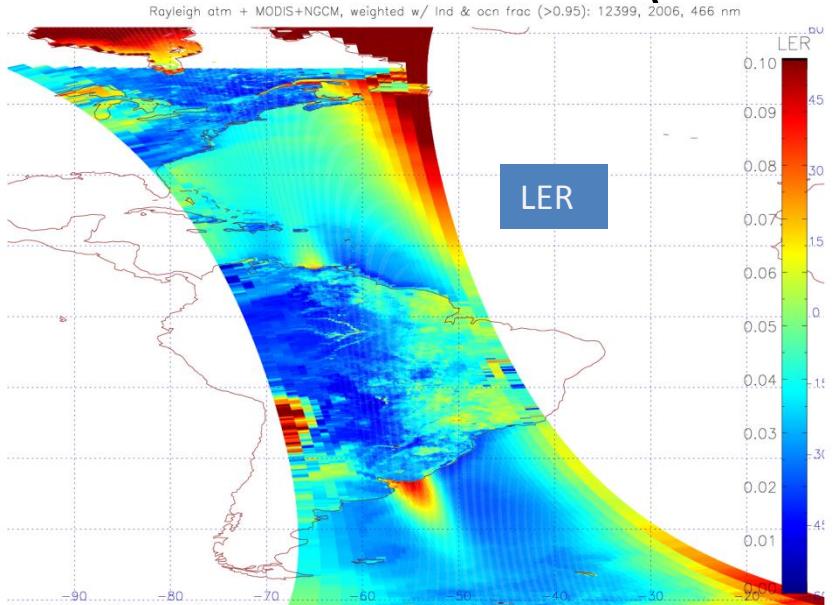
Pixel avg elevation for 2 OMI orbits



Notice the scale difference (5 km over 12399 vs 6 km over 12414)



BRF & its stdev, Water-leaving rad (466 nm, orbit 12399)



Things need to improve

- Ocean LER
 - Replace fixed wind speed (5 m/s) with variable ones (e.g., MERRA-2)
 - Option to speed up the process - replace online Vlidort RT calculations with LUT or neural network approach
- Land LER
 - Get BRDF coefficients over seasonal snow covers
 - Account for wavelength dependence of BRDF coefficients
- Study effects of aerosol & thin clouds on GLER

Backup slides

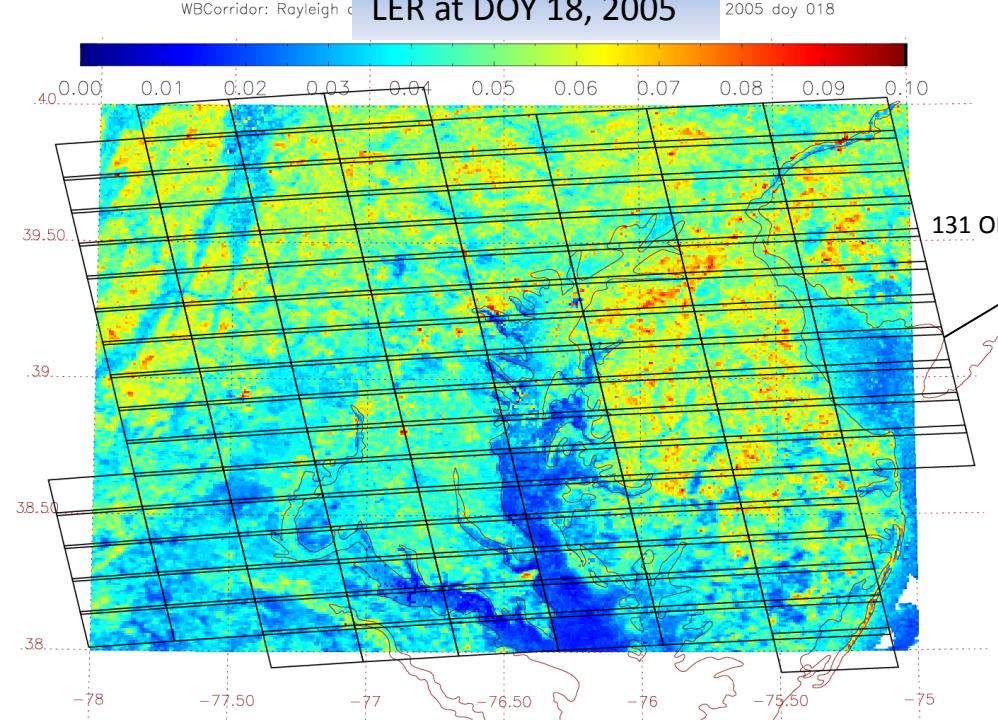
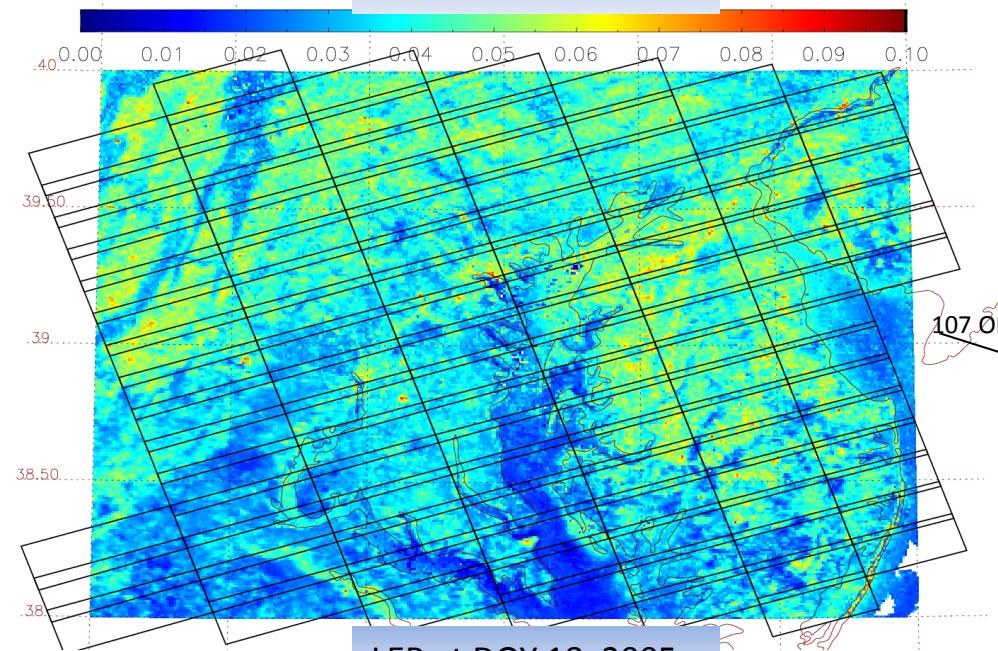


Background

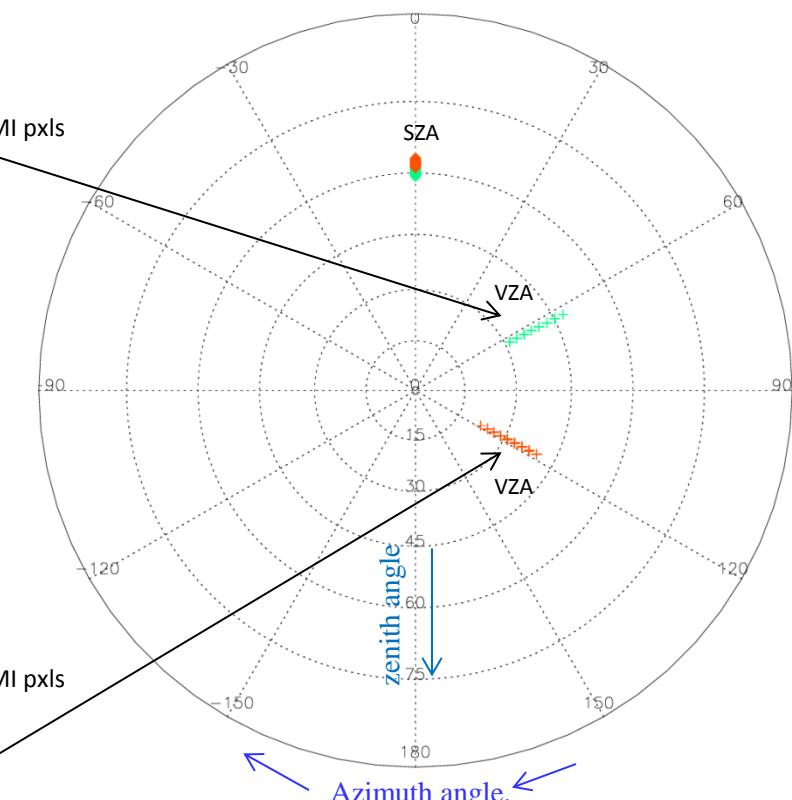
- Definition - LER (Lambertian Equivalent Reflectivity)
 - $I_a = I_0 + R \cdot T / [1 - R \cdot S_b]$ → $LER = 1 / [T / (I_a - I_0) + S_b]$
 - I_a , TOA rad
 - I_0 , atmos path-scattering rad
 - T and S_b are atm transmittance and multi-scat. refl btw the atm and the underlying sfc
 - Both I_a , I_0 and T are function of wv, solar & view angles, and sfc pressure
- Calculation – online or look-up-table (LUT) approach
 - LER components - I_0 , T and S_b
 - TOA rad (measurements or simulations)

WBCorridor: Rayleigh c LER at DOY 17, 2005

2005 doy 017



hi reso MODIS BRDF based LER at 466 nm w/ OMI pxl geometries under Rayleigh atmosphere



The cause: big diff in RAA
(relative azimuth angle)

DOY 17: RAA=60, fwd scat side

DOY 18: RAA=120, backwd scat side

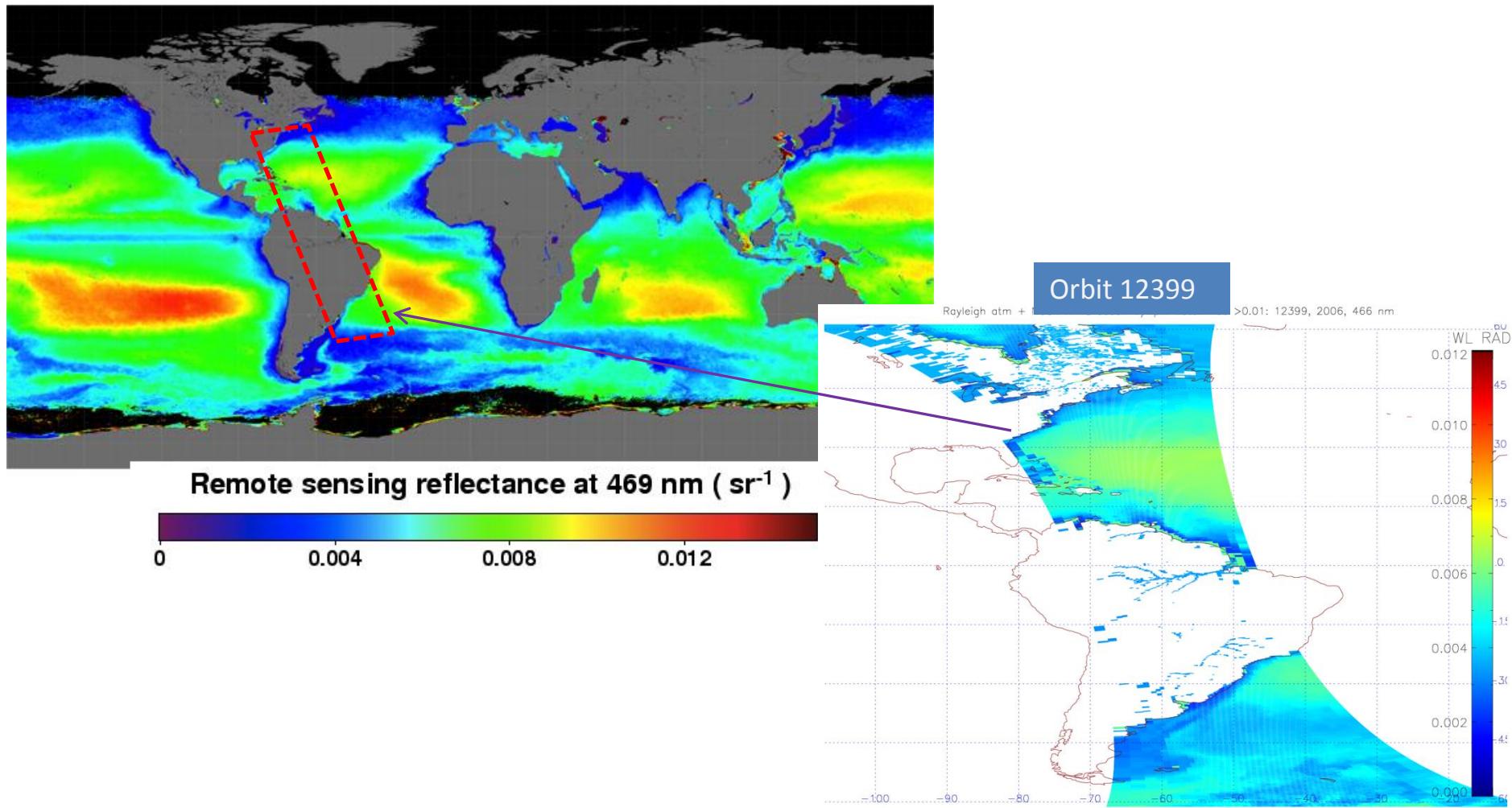
Outline

- OMI pixel-based BRF
 - Surface BRDF models
 - Land - MODIS kernel-driven BRDF model
 - Ocean - GISS Cox-Munk (CM) + water leaving contribution
 - Input datasets (OMI pixel averaged)
 - BRDF coeffs from MCD43GF (30 arc-sec, every 8-day) for land
 - Chl concentration (2.5 arc-min monthly climatology) for ocean
 - Accessory datasets
 - Land-Water fraction from MODIS LW mask (30-arc sec)
 - DEM data from NOAA NGDC DEM (2-arc min)
- Pixel-based LER
 - Vlidort simulation of TOA rad (I_a)
 - Atmos profiles (Rayleigh atm)
 - pixel-based BRF as the lower boundary
 - LUT for I_0 , T & S_b
- Applications
 - OMI NO₂ and Cloud retrieval algorithms
 - Details will be given in Vasilkov's talk, also in the paper (Vasilkov et al. in AMT, 2016)
 - OMPS and TEMPO algorithms (potential)

WL rad: OMI vs MODIS Climatology

Aqua MODIS: November climatology

http://oceancolor.gsfc.nasa.gov/cgi/l3/A20023052014334.L3m_MC_RRS_Rrs_469_9km.nc?sub=img



Surface type categories

- OMI L1B land-water flag
 - 0 - shallow ocean
 - 1 - land
 - 2 - shallow inland water
 - 3 - ocean coastline/lake shoreline
 - 4 - ephemeral (intermittent) water
 - 5 - deep inland water
 - 6 - continental shelf ocean
 - 7 - deep ocean
 - MODIS land-water flag (30 arc sec)
 - 0 - shallow ocean
 - 1 - land (Nothing else but land)
 - 2 - ocean coastlines and lake shores
 - 3 - shallow inland water
 - 4 - ephemeral water
 - 5 - deep inland water
 - 6 - moderate or continental ocean
 - 7 - deep ocean
- 

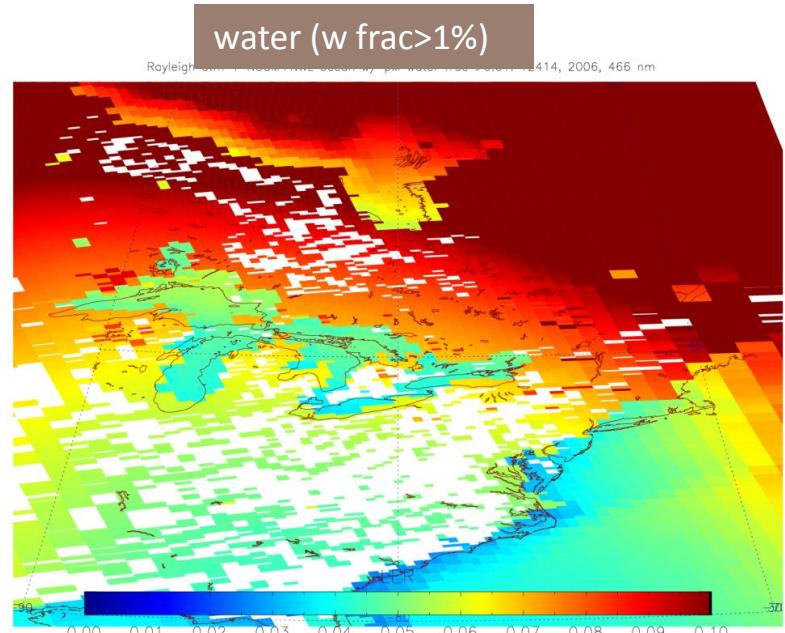
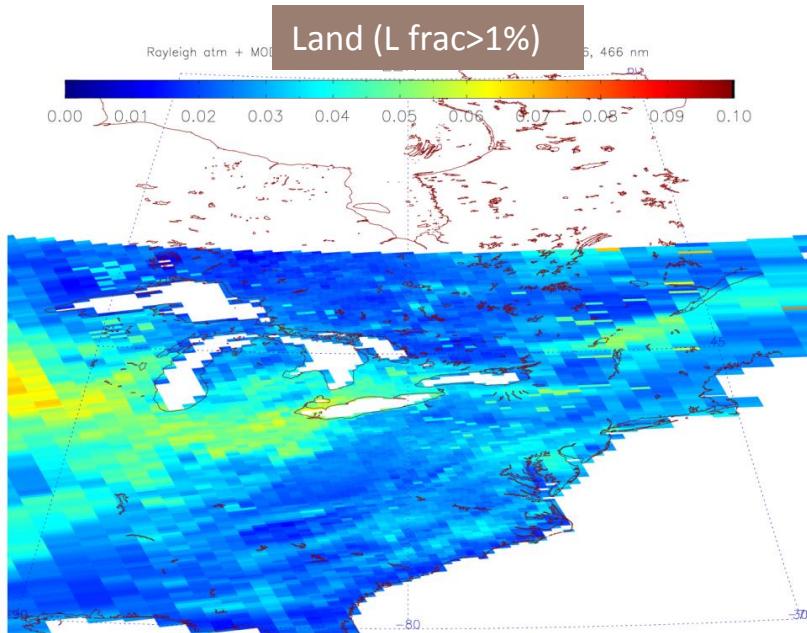
issues

- Unknown source and quality
- Cannot handle pixels mixed w/ different types
- See the following case studies

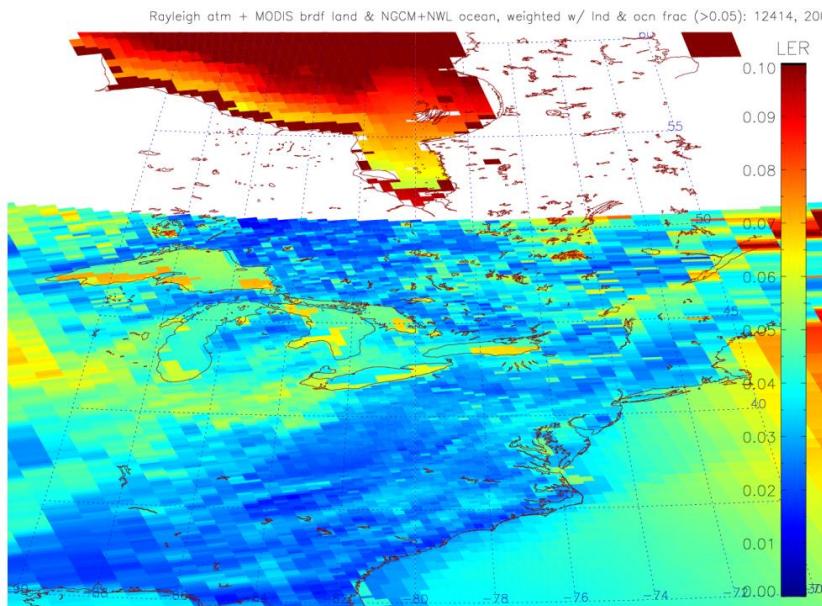
solution

- Use MODIS hi reso L-W flag data
- Treat flag 1,2 & 4 as land and others as water
- Obtain land fraction (f_L) by counting # of land & water Modis points in each OMI pxl

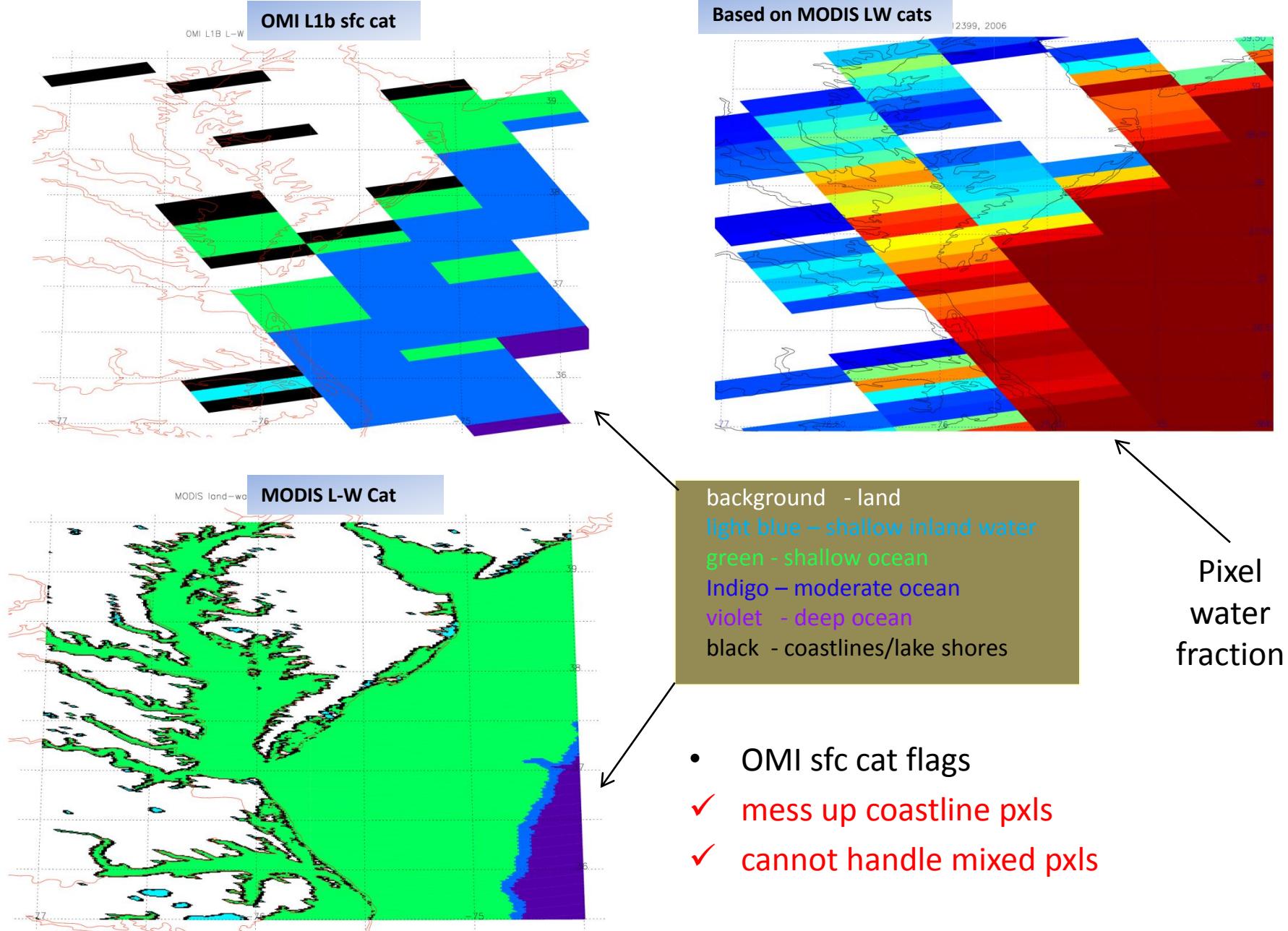
mixed pxl LER (orb 12414, N. Am)



Land-water
combined
(if L or W
fraction>5%)



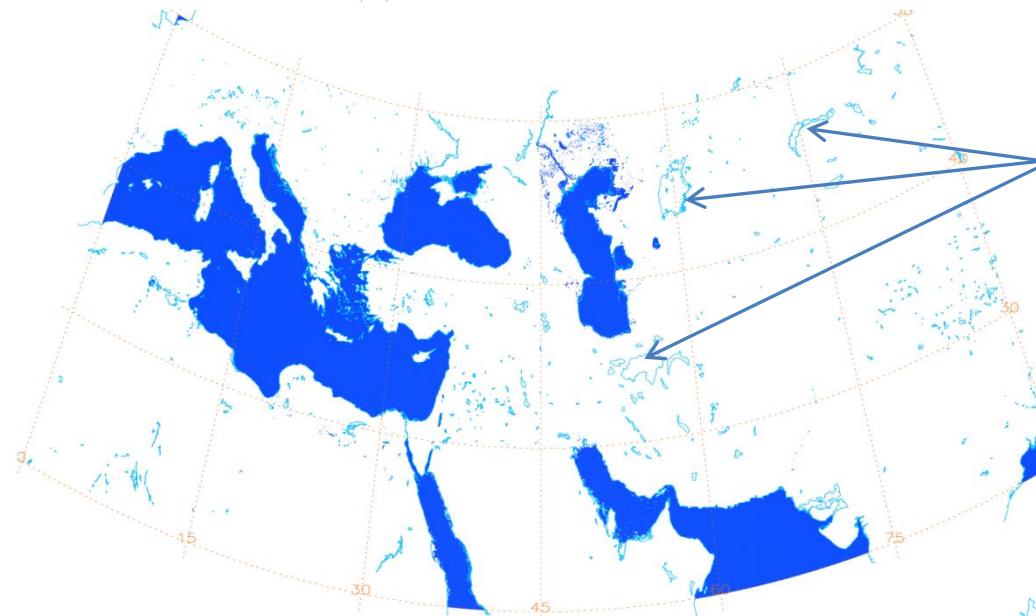
Case 2: Chesapeake bay area (orb 12399)



OMI pixel elevation estimation

- Pre-process 2 arc-min raw DEM data using MODIS 30 arc-sec L-W flag map
 - each DEM cell contains 4x4 Modis L-W flag values
 - keep all **negative** values over **land** and **positive** values over **inland waters**
 - zero out negative values over oceans
- Average pre-processed DEM elevation data over OMI polygon

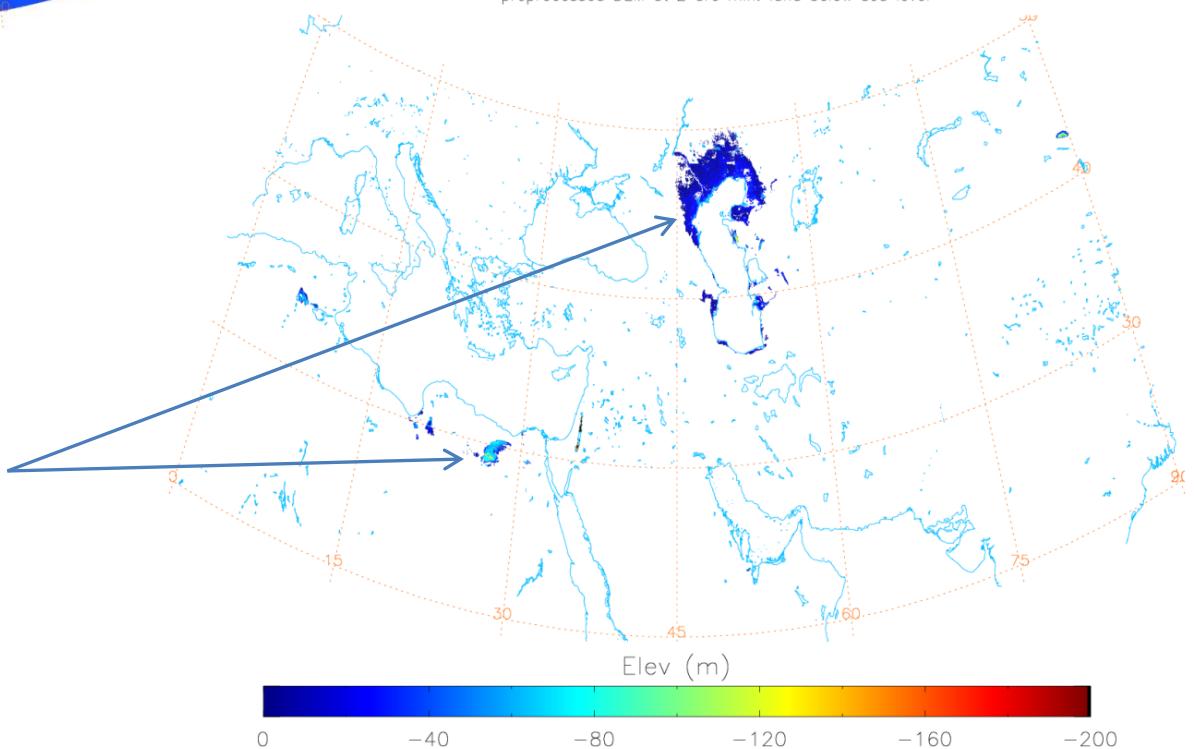
preprocessed DEM at 2 arc min: water at sea level



Lakes
above
sea
level

blue - water at sea level
white – land or inland
water above sea level
(background)

preprocessed DEM at 2 arc min: land below sea level



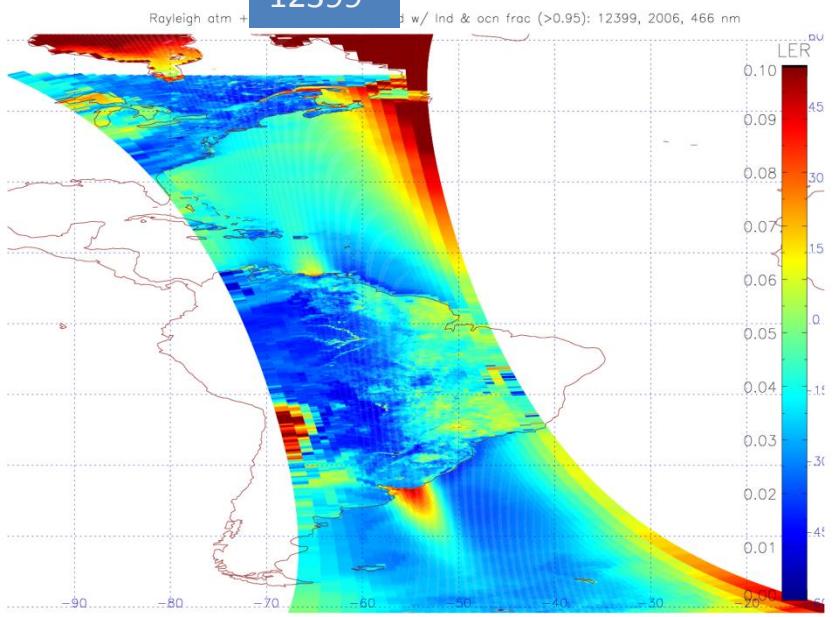
land below
sea level

Elev (m)

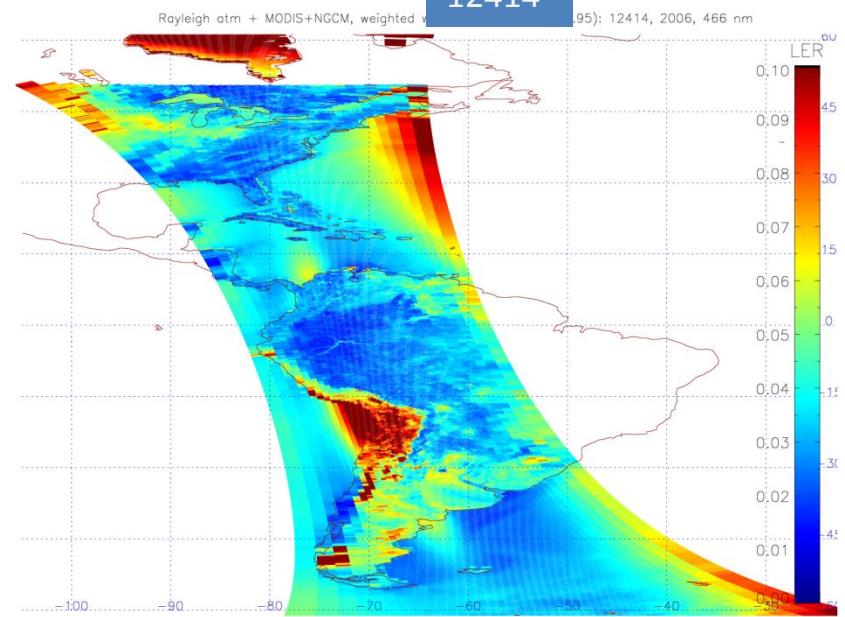
0 -40 -80 -120 -160 -200

Orbit-based LERs

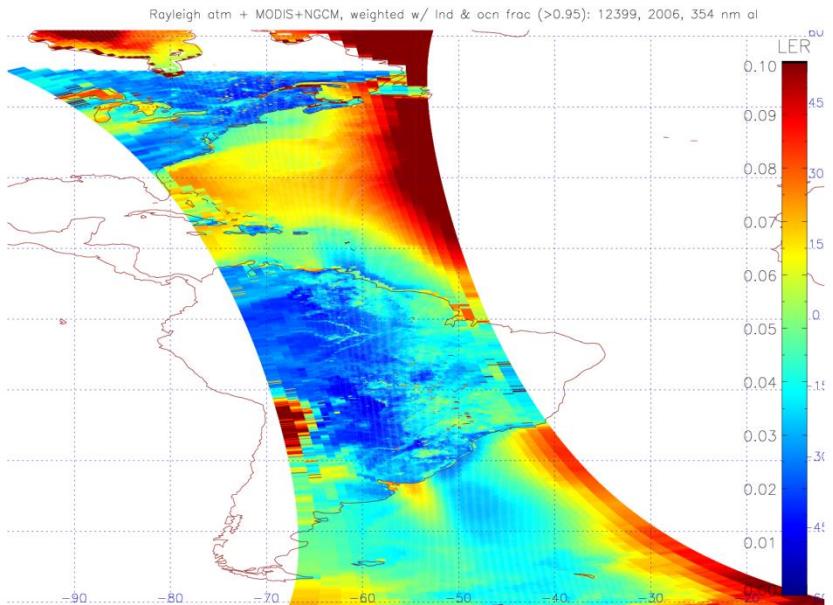
12399



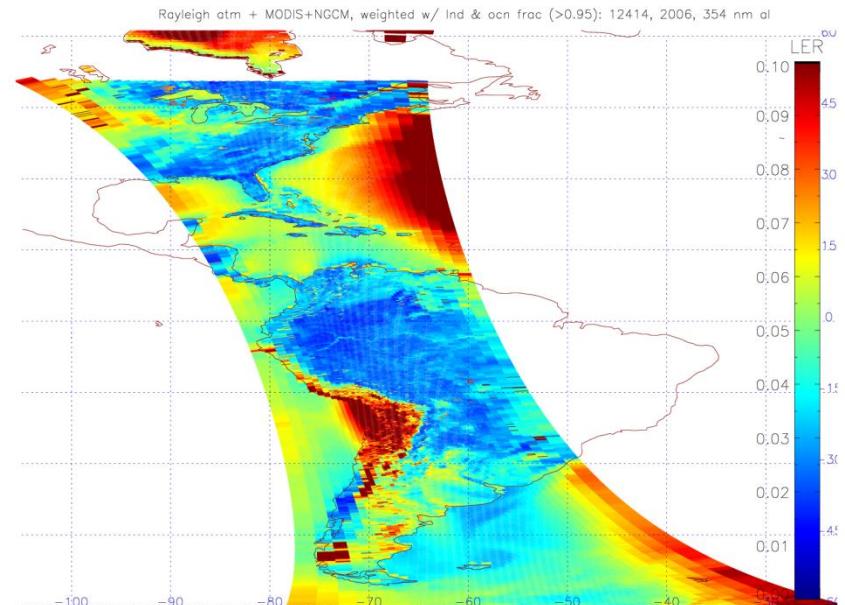
12414



466 nm



354 nm



Future work

- Neural network approach to obtain pxi LER for other satellites w/ similar pixel size
- Study effects of aerosol & thin clouds on LER
- Apply geometry-dependent LER method to other instruments (e.g., TROPOMI,OMPS NP, TEMPO)